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Pigeons' landmark use as revealed in a 'feature-positive', digitized landscape, touchscreen paradigm

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Abstract

Two pigeons were trained to discriminate between a S − (a digitized image of a grassy field presented on a computer monitor) and a S + (a digitized image of the same field containing a tree, a set of flowers, and a log). The location of the pecks to the images was recorded by a touchscreen. Both subjects quickly learned the discrimination and concentrated their pecks to particular 'landmarks', one pigeon pecking the flowers, the other the tree. This result suggests that the use of digitized images of real-world geographic locations may help us to understand how animals use visual landmarks in spatial navigation, and, in more general terms, how animals perceive and remember in their natural environments.

Key words: Feature-positive discrimination; Digitized image; Touchscreen; Landmark; Pigeon

Introduction

Many animals use visual cues ('landmarks') in the process of piloting to particular spatial locations. Cheng (e.g. Cheng, 1988, 1989) has developed both a paradigm to study animals' use of landmarks and a criterion for identifying whether a particular visual cue is a landmark. The procedures are simple: food is buried in a discrete, fixed location under the uniform substrate of an open field. Various objects, placed in fixed locations in the open

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field, serve as potential landmarks to enable subjects (hungry pigeons) to find the hidden food. Objects are identified as effective landmarks if the bird's searching behavior is shifted in the same direction, and to approximately the same extent, as a shifted object. The bird's searching behavior during both training and shift tests is measured using video tape from an overhead video camera. Use of this paradigm has led to the discovery of certain regularities in landmark use (e.g. landmarks closer to the goal are weighted more heavily than are distant landmarks – Cheng, 1989).

In the original version of the landmark paradigm the open field was a wooden-chip covered floor of a laboratory room (Cheng, 1988). Spetch et al. (1992; see also Spetch and Mondloch, 1993) have recently extended the paradigm to a computer-controlled VGA monitor/touchscreen apparatus. Hungry pigeons received food rewards for pecking at an unmarked location on the monitor. Landmarks were computer-generated graphics (a blue rectangle). Spetch et al. found that pigeons' use of landmarks in this apparatus was similar in many respects to that observed in the original open field version of the task.

The computerized landmark task has several advantages over the open field version, one of which is automated data collection by the touchscreen system which records the XY coordinates of each peck. Another advantage is that computers are capable of presenting large, high quality, colored images. In recent research we (Spetch and Wilkie, in press) have extended the Spetch et al. (1992) touchscreen procedure to one in which pigeons view a digitized image of an actual outdoor location (a grassy field) such as might be encountered by a feral pigeon. Again, the pigeons are trained to peck at an unmarked spot on the monitor. In that research it was found that pigeons use certain parts of the scene (e.g. a tree) as landmarks to locate the hidden goal. Peck location was shifted when the landmark was shifted, demonstrating control of search behavior by the landmark.

In the present paper we report a further extension of this research. One goal of the research is to provide another, complementary, type of evidence of landmark use by animals. A second, and more important, goal is to develop a paradigm in which an animal's responding to the image of a digitized outdoor scene can indicate what components, parts, or features of real-world scenes are attended to. As in our other recent work (Spetch and Wilkie, in press) we use computer generated images of outdoor scenes on a touchscreen-equipped monitor. One of the constraints inherent in the search paradigm is that pigeons tend to rely on visual cues closest to the target location as landmarks. Thus, which cues act as landmarks to guide search behavior may be determined more by spatial proximity rather than natural saliency. In the present research we attempted to remove this constraint and permit subjects to show us which part(s) of an outdoor scene are most salient.

We attempted to do this by using a procedure similar to the 'feature-positive' discrimination procedure first reported by Jenkins and Sainsbury (1969) and later elaborated upon by Edwards and Honig (1987). Jenkins and Sainsbury (1969) trained pigeons to discriminate between a S+ and a S− differentiated only by a single feature (e.g. three circles vs. two circles and a star). Two groups of pigeons were tested, one in which the feature was on the S+, and a second in which the feature was on the S−. The feature-positive group learned the discrimination much more rapidly than the feature-negative group. The explanation for this 'feature positive effect' was discovered when the location of the pigeons' pecks to the displays was recorded. Feature-positive subjects were found to localize their pecks on the distinctive feature before eliminating responses to the S−. Feature-negative subjects, on the other hand, only gradually eliminated responding to the feature and localized responding on the common features of the two displays. The same general pattern of results was reported by Edwards and Honig (1987) who trained pigeons to discriminate complex visual images. Their stimuli were photographic slides of a scene with a person present, and the same scene with the person absent. Groups of pigeons were trained to discriminate this 'present/absent' category with the feature (person) either serving as S+ or S−. Again feature-positive subjects learned more rapidly.

For the purposes of our research the important finding of Jenkins and Sainsbury (1969) was that pigeons physically peck at the distinguishing feature of the S+. In the present research we used this phenomenon to see what aspects of an outdoor scene are treated as features (i.e. are pecked at) by pigeons. Pigeons were trained on a two-image discrimination of an outdoor location. The S+ image was a grassy field containing a small tree, a planter containing flowers, and a log. The S− was the field with the tree, flowers, and log removed. A touchscreen was used to record the location of pecks to the two images.

Materials and Methods

Subjects

The subjects were one homing pigeon (Sulu), and one Silver King pigeon (Mel), both of whom had participated in previous experiments unrelated to the present, and in different apparatus than that employed in the present experiment. The subjects lived in large plastic-coated wire mesh cages in a climate-controlled colony (20°C) that had a light : dark period matched to natural sunrise : sunset times. Subjects had free access to vitamin-(Nekton-K) fortified water, crushed oyster shells, and granite grit. The subjects received sufficient mixed grain during experimental sessions and post-session feedings to maintain their body weight at approximately 95% of free-feeding weight.

Apparatus

One end of a 35.5 cm (W) by 31.5 cm (H) by 45.5 cm (L) clear Plexiglas chamber contained an opening that abutted to a Zenith Model 1492 14-inch (20.5 cm vertical, 27 cm horizontal) flat screen VGA computer monitor, the screen of which was covered with a 2 mm sheet of clear Plexiglas. A Carroll Touch Inc. Model 8001-4216-02 touchscreen was mounted on the Zenith monitor. The other end consisted of a sliding door through which a subject was introduced to, and removed from, the chamber. This end wall also contained an opening providing access to a standard grain feeder hopper.

The monitor was operated in VGAHI mode (640 by 480 pixels, 70 Hz refresh rate, 256 colors) by a Diamond Speedstar VGA video card. The touchscreen, capable of decoding 1230 points (41 horizontal by 30 vertical), provided 'touch' information (push, move, or release). The array of light emitting diodes on the touchscreen were about 1.6 cm from the monitor screen.

A 386 computer controlled stimulus presentation on the VGA monitor, monitored touchscreen activity, operated the grain feeder when appropriate, and recorded data on a floppy disk and to a remote networked 486 server computer. This controlling computer was programmed using Borland Turbo C++.

Stimuli

To capitalize on the feature-positive discrimination procedure, the S + and S − images had to have approximately the same background. To facilitate editing of the images the background had to be reasonably uniform and textured. We chose a flat playing field covered with short grass and some small bare spots as a background. For 'landmarks' a small potted Douglas Fir tree, a planter containing a variety of flowers, and a log were chosen because they were about the same general size, and could conveniently 'fit' onto the background.

Panel A in Figs. 1 and 2 show black and white pictures of the S + images that were used in the experiment. Several steps were involved in generating the digital images for presentation on the Zenith monitor. First, a SVHS video tape was made of the outdoor landscape with a JVC Model GF-S550 industrial camcorder. Next, the video tape was viewed and two frames was selected to be the S + . These frames were digitized using New Media Graphic's Super VideoWindows multimedia card and software. Next, the Copy and Paste functions were used to create a the S − image. This was done by copying grassy areas from the areas immediately adjacent to the 'landmarks' in Image 1 and then pasting these areas on top of the landmarks, producing a grassy field without landmarks. Finally, the Computer Presentations' ImagePrep graphics utility were used to produce the 640 × 480 × 256 color GIF format (Compuserve Inc.) images that were displayed by C + + software.

Preliminary procedures

Because both subjects had prior experimental experience, little preliminary training was required. Subject Mel received a few sessions in which he was autoshaped to peck at an image on the VGA monitor that was different than the ones used in the experiment proper (a pair of seagulls). This image was used to ensure that preliminary training would not bias the subject to peck at certain features in the images used in the experiment proper. During these sessions an 8-s presentation of the image was followed by 4-s of access to mixed grain. Pecks at any part of the image turned the stimulus off and immediately operated the feeder. Once subject Mel was reliably pecking at the screen, food was made response contingent. Subject Sulu was first hand-shaped to peck at a blue square (about 3 by 3 cm in size) located in the center of the monitor and then received training similar to subject Mel. Once the birds were reliably pecking at the screen, the experiment proper began.

Experiment proper

The experiment consisted of three phases. In the first, which lasted 30 sessions, the subjects were taught to discriminate between the S + and S − images. In the second and third phases, the XY coordinates of each peck to the images were recorded to determine which part of the image was being responded to. Subject Sulu received Image 1 as the S + in Phase 1 and 2 and Image 2 in Phase 3; subject Mel received the opposite order. Two S + images were used to see if subject's pecking behavior tracked the displacement of the landmark(s) in the two images. In all three phases, subjects generally received sessions in the mid-mornings, 5 days per week. The experiment proper began on December 15, 1992

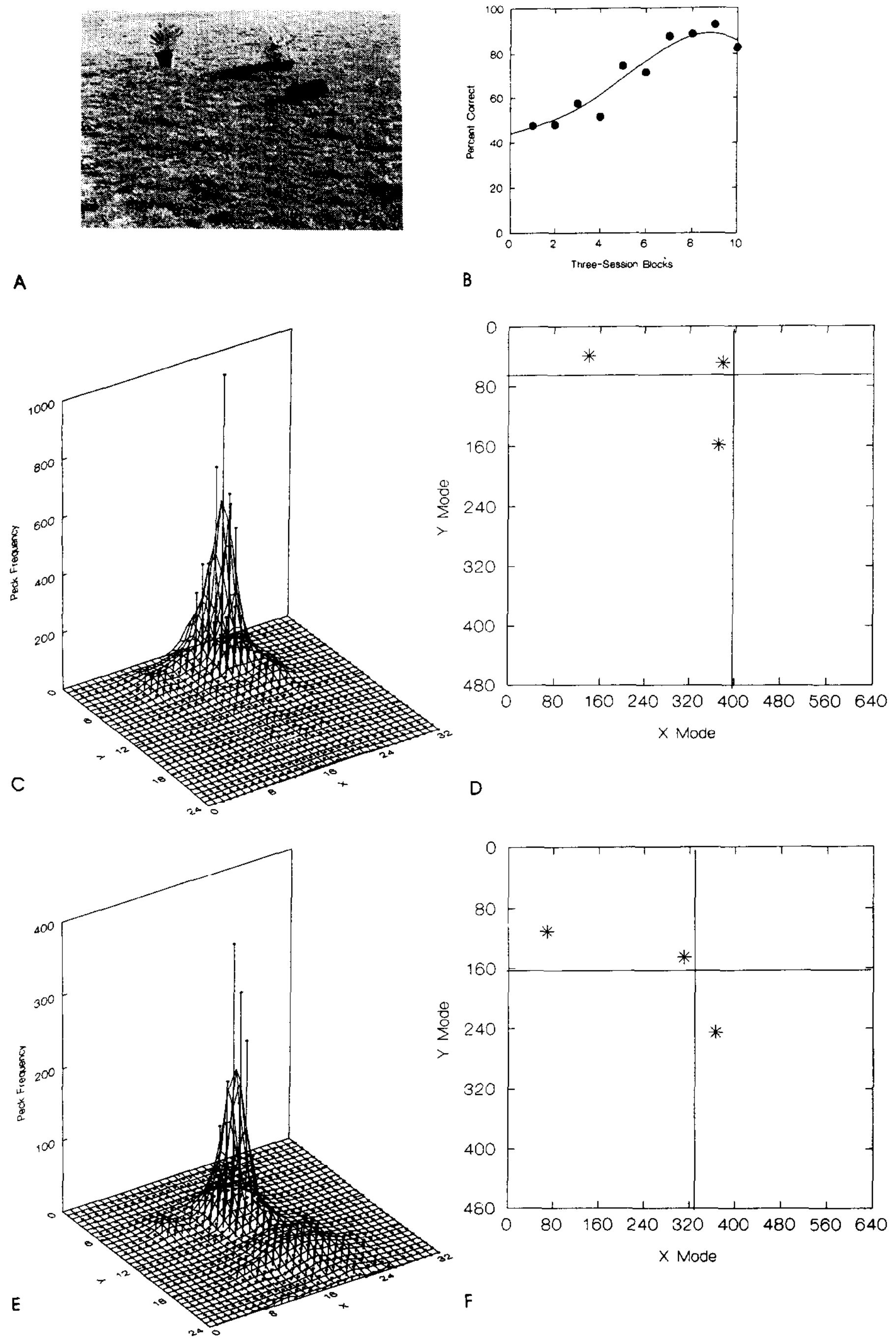

Fig. 1. Panel **A** shows Image 1 S+. The remaining panels show data for subject Sulu: Panel **B**, acquisition data; Panels **C** and **E**, peck frequency to various parts of Image 1 and 2 respectively; Panels **D** and **F**, modal XY values of distributions shown in Panels **C** and **E**. The * points in the latter plots show the center of the three landmarks.

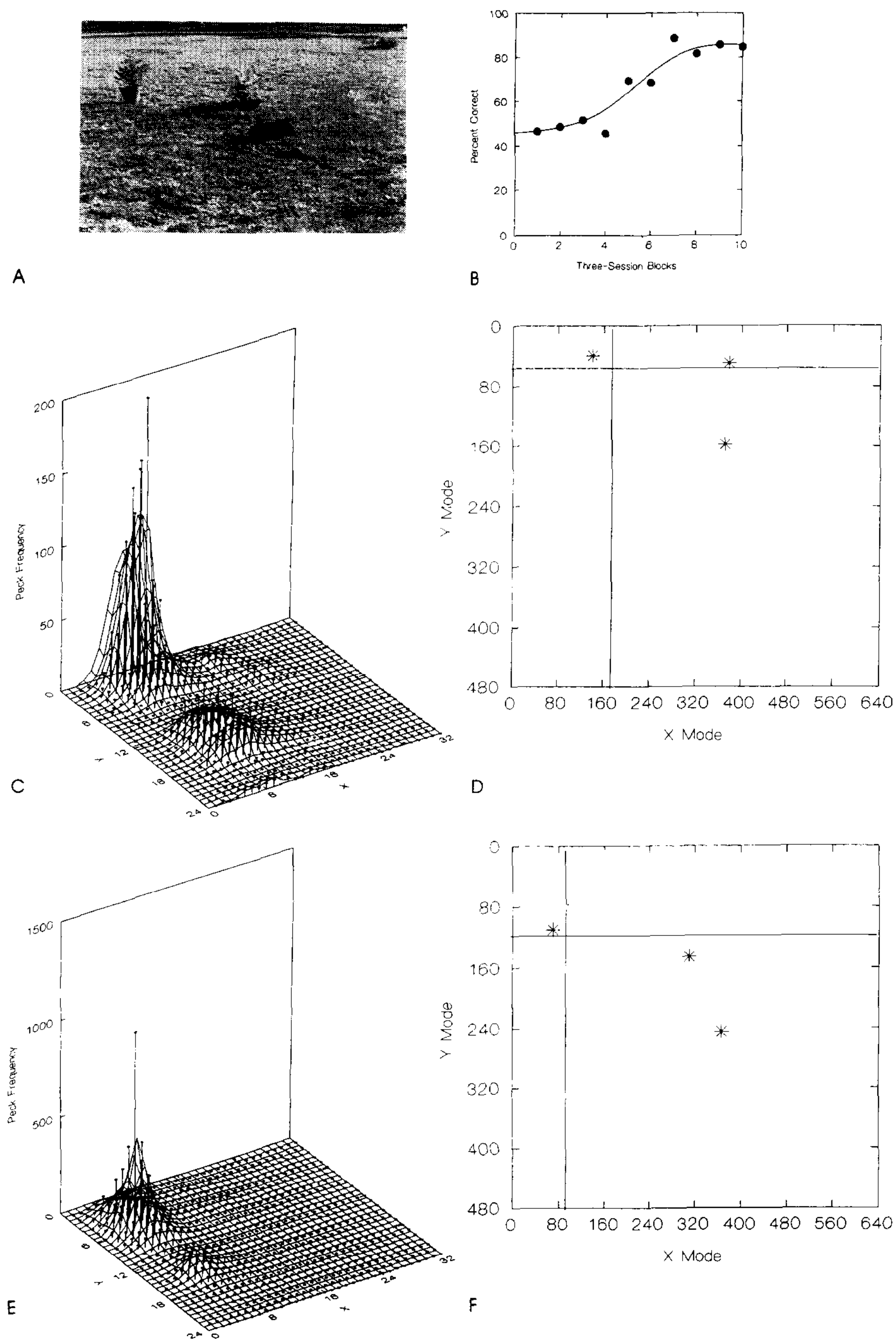

Fig. 2. Panel **A** shows Image 2 S+. The remaining panels show data for subject Mel in an identical format to the data in Fig. 1.

and ended on June 7, 1993. During this period sunrise:sunset times in Vancouver varied from 08:01–16:14 to 04:09–20:14 Pacific Standard time. (Data provided by Atmospheric Environment Service of Environment Canada.)

Acquisition

During acquisition sessions, subjects received 30 trials. Trials were separated by a 10-s intertrial interval, spent in darkness. On each trial, the probability was 0.5 that the trial would be a S + trial. Both S + and S − trials lasted for 12 s. On S + trials, the first peck after the completion of the 12-s interval turned off the display and immediately produced a 4-s grain reward. On S − trials the display was turned off after the expiration of the 12-s interval. It is important to note that reinforcement for pecking the S + image was not contingent upon the peck being in any particular area on the screen; pecks to any part of the S + image produced food. During these sessions the controlling computer recorded the total number of pecks to the S + and S − images. These data were used to calculated a percent correct score (percent of total pecks made to S +) for each session.

XY coordinates data acquisition

These sessions were similar to those in the acquisition phase except that the XY coordinates of each peck to the S + and S − images generated by the touchscreen were recorded on a local floppy and on a remote server. Subject Sulu received 40 sessions with the Image 1 as the S + and then 21 sessions with Image 2 as the S + . Subject Mel received 55 sessions with Image 2 and then 18 sessions with Image 1. The two images were employed to see if peck location tracked the location of landmarks in the depicted outdoor scene.

The XY coordinate data were analyzed using the Minitab statistical package on a networked Sun/Unix computer and plotted using Systat for Windows (Systat Inc., 1992). For the purposes of plotting, the 640 by 480 XY matrix (307,200 cells) was reduced to a 32 by 24 matrix (768 cells) by dividing the XY coordinates by 20. Thus each cell represents a 20 by 20 pixel area.

Results

Acquisition

Panel B in Figs. 1 and 2 show acquisition data for subjects Sulu and Mel, respectively. Percent correct responses to the S + image is shown for three-session blocks. The smooth line was fitted using Systat for Window's distance weighted least squares.

Both subjects acquired the discrimination at similar rates and reached similar levels of correct performance. Not readily apparent in these figures is the rapidity at which this discrimination was acquired. Recall that subjects received 30 trials each session, with the image being presented for 12 s on each trial. Thus in each session the subjects received a total of 6 min of exposure to the S + and S − images. As can be seen in Figs. 1 and 2 acquisition in both subjects seemed to be well under way by the fifth block of sessions (i.e. after only 30 min of discrimination training). This result suggests that discriminations of complex, naturalistic images may be acquired more rapidly than discriminations involving simple, but arbitrary, stimulus material. Additional experimental work is obviously required before such a claim could be substantiated, however.

Peck location data collection

Over the 40 sessions with the first image Sulu pecked 13 183 times, 85% of which were directed to the S + . Over the 21 sessions with the second image this subject pecked 5426 times, 90% to the S + . The corresponding values for Mel were 55 sessions, 12, 073 pecks (83% correct) and 18 sessions, 5460 pecks (78% correct). Thus discrimination performance remained good in these phases of the experiment.

Table 1 provides a quantitative summary of the data collected in the second and third phases of the experiment in which the XY coordinates of each peck to the S + and S − stimulus was recorded. It is important to note that the upper left of the image/touchscreen XY coordinate system is 0,0 and that the lower right is 640, 480. The table shows the mean and standard deviation values of the X and Y coordinates of pecks directed at both the S + and S − images. If subjects responded randomly over the whole screen the mean X and Y values would be 320.5 and 240.5 respectively $[(1 + 2 + 3 + \ldots + 640)/640 = 320.5;$ $(1 + 2 + 3 + \ldots + 480)/480 = 240.5]$. The corresponding SDs would be 184.9 and 138.7. On the S − image the mean X and mean Y coordinate values of pecks was reasonably close to these values (mean X over all conditions was 310, mean Y over all conditions was 285). This result suggests that the subjects were more or less responding in a random manner to the S − image. However, the fact that the calculated S.D. was consistently less than expected from chance responding suggests then that was not strictly the case.

The S.D.'s of responding to the S + images were consistently smaller than those to the S − image showing that pecks to these images were more concentrated spatially.

The mean X and Y coordinates on S + trials were different for the different subjects and differed between Image 1 and Image 2. This pattern of results suggests that (a) the subjects were concentrating their pecking at different parts of the S + image, and (b) that the center of this concentration of pecks moved when the subjects were switched from Image

TABLE 1

XY coordinate data

Sulu	Image 1			
	Mean X	Mean Y	S.D. X	S.D. Y
S+	371	104	75	82
S−	365	218	153	100
Sulu	Image 2			
S+	332	240	71	101
S−	388	325	138	106
Mel	Image 2			
S+	136	141	67	87
S−	229	280	100	139
Mel	Image 1			
S+	191	129	71	127
S−	259	238	106	140

1 to Image 2 and vice versa. By carefully examining the mean XY coordinate data and the actual images shown in Figs. 1 and 2 one can see that subject Sulu's mean XY coordinates in both images are in the vicinity of the flowers while subject Mel's mean XY coordinates are in the vicinity of the potted tree. To better display this key result, a graphical analysis is also presented to complement the quantitative analysis.

Panels C and E in Figs. 1 and 2 show peck frequency to various parts of the monitor, in 20 pixel bins, to the S + images. These plots were generated by dividing the XY coordinates of each peck by 20 and then summing the number of pecks that fell in each of the 32 by 24 bins. A vertical line in each bin shows the frequency of pecks in that bin. A surface was fitted to the peck frequency data using the distance-weighted least squares options in the Systat for Windows. These plots clearly show that both subjects concentrated their pecks in specific parts of the S + images: Sulu in the region of the flowers, Mel in the region of the tree. These 'landmarks' are lower on the screen in Image 2 than in Image 1, and the peck distributions shift correspondingly. Pecks to the S − images occurred much less frequently and were not concentrated in any one part of the screen.

Panels C and E contain a very interesting and important result that is easily overlooked; both birds, in both S + images, show a very extreme modal peck frequency. One bin is very much higher than all the others. This effect does not 'pop out' because it is only one point among 767 others. The XY coordinates of the mode of each of the distributions shown in Panels D and F (converted back into the 640 by 480 format). The vertical and horizontal lines in these plots show the modal X and Y values, respectively. The star symbol shows the 'center' of the tree (top left), flowers (top right), and log (bottom right). These center values were found by programming the touchscreen to record XY coordinates as the outline of each the three landmarks was traced with a pencil. The resulting XY coordinate values for each landmark were then averaged to produce the point represented by the star (*) symbol. Panels D and F clearly show that the modal values are very close to the centers of the landmarks. It is clear that the subjects were not just pecking in the general vicinity of a landmark but rather, most times, seemed to be pecking specifically at the landmark. These plots also show that the mode shifts when the location of the landmark on the screen shifts.

Table 2 shows the numerical values of the modes of displayed graphically in Figs. 1 and 2. For example, subject Sulu made 11 205 pecks to Image 1 S + (85% of 13 183 = 11 205). Of these 992 were directed at the X = 20, Y = 3 bin. This table also provides an indication of the statistical improbability that such a modal score could simply be a chance occur-

TABLE 2

Mode data: The XY coordinate values are those from Figs. 1 and 2

Mode Pecks	X Coord.	Y Coord.	Z score
Sulu	Image 1		
992	20	3	856.2
Sulu	Image 2		
369	17	8	525.6
Mel	Image 2		
13,27	5	6	759.5
Mel	Image 1		
197	9	3	375.4

rence. Under a null hypothesis assumption that peck location is distributed randomly there should be an equal number of pecks in the 32 by 24 (768) bins. For example, for subject Sulu these should be 14.5 pecks in each bin (11 205/768). The modal bin, however, contains 992 pecks. Using a binomial distribution with $P = 1/768 = 0.0013021$, $Q = 1\text{-}P = 0.9986979$, and a standard deviation of the square root of NPQ, the Z score for subject Sulu's 992 pecks is $[(992-14.5)/1.13] = 856.2$. Similar improbable extreme values occur for the second image and second subject.

Summary

Both subjects readily discriminated the S + and S − images. After several sessions of discrimination training, subjects pecked infrequently at the S − image. The location of pecks to the S − image were quite variable. Pecks to the S + images, on the other hand, were very spatially concentrated. Subject Sulu pecked in the vicinity of the flowers while subject Mel pecked in the vicinity of the tree. Both subjects pecked the S + images most frequently in a very small area (1 bin, 20 by 20 pixels, less than 1 square cm) near the center of the landmark. Peck distributions shifted as landmark location in the S + image was shifted, satisfying the criteria for landmark identification.

Discussion

The present research, as well as that of that reported by Spetch and Wilkie (in press), demonstrate the feasibility of using digitized images of videotaped outdoor scenes as stimulus material in experiments that attempt to understand how animals, and in particular pigeons, use visual cues as landmarks. The potential of this technology is enormous, both in this particular area of research and others that attempt to understand the perceptual and cognitive abilities of animals. Consider the following. One of the best criteria for whether a cue is attended to and used as a landmark is that some behavior exhibited by our subjects shifts in a predictable manner when the landmark is shifted in space. With the 'staged' outdoor scene used in the present experiment, it would have been possible to have physically moved the tree, flowers, or log during production of the videotape from which the digitized images were created. However, with more natural outdoor landscapes, that include large trees, buildings, bodies of water, mountains, etc., such is obviously not possible. On the other hand, image manipulation software such as used in the present research permits extremely simple and rapid creation of images in which cues are shifted. This technology will permit analysis of landmark use in a variety of complex, naturalistic, outdoor locations. As well as spatial location of cues, size, orientation, color, contrast, and many other properties can also be readily manipulated.

The present research also demonstrates the feasibility of using touchscreen technology in conjunction with a procedure similar to 'feature positive' discrimination as a way of assessing which feature(s) of complex, naturalistic, outdoor environments subjects attended to. The present procedure capitalized on the tendency of pigeons to peck at the distinguishing feature of the S +. Both pigeons in the present experiment pecked at the S + image of the outdoor landscape with remarkable specificity. The present results suggest that this paradigm may be capable of detecting even very small and subtle features depicted in the digitized image.

The present procedures have one main advantage over the hidden target landmark task previously developed to study landmark use by animals. In that task pigeons tend to use cues that are in close spatial proximity to the goal location as landmarks (e.g. Cheng, 1989). Cues that are naturally more salient may not be used because, being more distant, they provide less accurate information about the spatial location of the hidden target. The present procedures may be capable of providing a truer measure of what cue(s) in these complex landscapes are attended to when animals view these scenes. In Spetch and Wilkie's (in press) experiment using a hidden target on an image similar to the S + images in the present, spatial proximity seemed to determine what cue was used as a landmark to locate the hidden goal. For example, all birds that searched for a goal nearest the tree used the tree exclusively as a landmark. One of the subjects in the present experiment pecked at the tree but the second bird clearly demonstrated that it found the flowers a more salient cue. In future research it will be important to attempt to determine the properties that control landmark saliency. Using landmarks that varied in both color and shape, Spetch and Mondloch (1993) found that color but not shape controlled search behavior. It is not yet clear whether that effect will extend to the present paradigm. In any case, the present finding of idiosyncratic landmark use by the two subjects demonstrates the potential advantage of the present paradigm over the hidden goal task.

The idiosyncratic landmark use in the present experiment may be a consequence of the fact that all three landmarks were roughly equivalent in saliency. In constructing the videotaped scene no attempt was made to deliberately vary landmark saliency. In 'unstaged' naturalistic landscapes, there are probably many more potential landmarks. When images of these landscapes are used, orderly hierarchies of cue use may emerge and idiosyncraticity may disappear. On the other hand, it is possible to imagine that experience, development, and other factors would lead to individual differences in landmark use.

Both pigeons in the present experiment responded more-or-less exclusively to one landmark. Pecks that did not strike the landmark fell nearby rather than at the location of a second, or third landmark. It will also be important in future research to determine if this single landmark response always occurs. It may turn out to be the case that the present paradigm reveals only the most prominent landmark in a scene. However, it is probably premature to reach such a conclusion. If multiple landmarks are used it will be important to determine the nature of subjects' behavior in such a situation. A bimodal distribution of pecks, with the modes centered at landmarks, would be unambiguous evidence of the use of two landmarks. Another outcome may also point to multiple landmark use – a peck distribution that is not centered on any one landmark, but is peaked midway between two landmarks. In both cases, landmarks would be unambiguously demonstrated if the locations of these peaks shifted as the location of the landmarks in the images were shifted, as happened in the present experiment.

There are several other interesting and important directions for future research using variants of the present procedures. One concerns pigeons' recently demonstrated ability to form conceptual discriminations of outdoor geographic locations. Honig and Stewart (1988) trained pigeons to discriminate between color photographic slides of two outdoor locations on a university campus. Wilkie et al. (1989) trained homing pigeons to discriminate color photographic slides of a large area surrounding their loft from other slides taken at locations that they had not seen during homing flights. Kendrick (1992) trained pigeons to discriminate between two views of the areas outside of two windows in a building in which the pigeons lived. The conceptual nature of the discrimination in all three experiments was demonstrated by the successful transfer of the discrimination to novel, nonreward slides depicting the S + and S − locations. Presentation of digitized images of these broadly-defined spatial locations on a touchscreen-equipped monitor that measures peck location may extend our understanding of how animals recognize places. At present we know that animals can recognize spatial locations depicted photographically, and, because they can successfully classify novel instances of the locations, that this recognition is conceptual in nature. We also know that while experience with the outdoor spatial location may somewhat facilitate such learning (see, for example, Wilkie et al., 1992), such experience is not necessary for place recognition learning. In both the Honig and Stewart (1988) study and the Wilkie et al. (1989) study pigeons who had no outdoor experience with the locations depicted in the discriminations still learned these discriminations. It seems that training with several 'snapshot' views of a location is sufficient to lead to place recognition (Honig and Stewart, 1988). What is still not known is what stimulus features in the depicted scenes are important for the correct discrimination of location. By examining the location of pecks to digitized images of outdoor spatial locations progress in answering this question may be made.

Another issue for future research will be the examination of the relationship between discrimination and directed pecking. Although it seems probable that the pecked at features are the ones that control discrimination between S + and S − it is possible for other relationships to exist. For example, the present pigeons may have used all three landmarks (and perhaps relational information as well) to make the discrimination but only pecked at the most prominent landmark.

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